PROPOSAL TO
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
FOR CONTINUATION OF A GRAZING INCIDENCE IMAGING TELESCOPE
FOR X-RAY ASTRONOMY USING SOUNDING ROCKETS

Continuation of Grant NSG 5091

P 589-1-76

For the period 1 July 1976 to 30 June 1977

(NASA-CR-156695) PROPOSAL TO NATIONAL AERONAUTICS AND SPACE ADMINISTRATION FOR CONTINUATION OF A GRAZING INCIDENCE IMAGING TELESCOPE FOR X-RAY ASTRONOMY USING SOUNDING ROCKETS (Smithsonian Astrophysical   N78-20027
HC A04/MF A01
Unclas
G3/89 07310

January 1976

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
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1. INTRODUCTION

This proposal is for continuing support of a sounding rocket program in celestial X-ray astronomy at the High Energy Astrophysics Division of Smithsonian Astrophysical Observatory (SAO). The program is one which has been underway for several years and is currently in progress under NASA Grant NSG5091.

We propose here to complete the construction of a high resolution imaging telescope experiment payload suitable for launch on an Astrobee F sounding rocket. Also the integration, launch and subsequent data analysis effort are part of the statement of work of this proposal.

The payload will utilize major component subassemblies from the HEAO-B satellite program which are non-flight development units for that program. These are the X-Ray Test Mirror (XTM) and High Resolution Imager (HRI) brassboard detector. The properties of the mirror and detector are discussed in Section 3 of this proposal. The availability of these items for a sounding rocket experiment has been explored with the HEAO-B project office and a letter of position affirming that the XTM and HRI can be incorporated into the proposed payload is included in Appendix A.

The schedule shown in Section 4 of this proposal reflects the expected transfer of the XTM for the HEAO-B program to the rocket payload.

2. SCIENTIFIC OBJECTIVES

Several types of objects are particularly well suited for study with this new payload. First, with an angular resolution of better than 5 arc seconds for sources within 5 arc minutes of the optical axis, the telescope is uniquely suited for studying the structure of relatively young supernova remnants such as the Crab, Cas A, and possibly Tycho. Figure 1 shows the X-ray location for Cas A superimposed on the radio contours indicating the complex structure of the source over a size of $\sim$ 5 arc minutes. Gorenstein, Harnden, and Tucker (1974) describe a shockwave model for the expansion of supernova remnants into the interstellar medium and interpret the Cas A X-ray observations of Fabian, Zarnecki, and Culhane (1973) showing a size of 5.5 arc minutes in terms of this model. Observations with the payload proposed here would yield a count rate of $\sim$ 2 counts/sec from Cas A and $\sim$ 50 counts/sec from the Crab Nebula with an angular resolution of $\sim$ 5 arc seconds. With 200 seconds of observation, a central point source component of Cas A containing 10% of the total X-ray emission would be detectable at the $\sim 6\sigma$ level. Details on the actual distribution of X-rays including the size and shape of a suggested shell would be readily available. Similarly, with a short observation ($\sim$ 30 seconds) of the Crab Nebula X-ray source, we would obtain valuable information on the distribution of X-rays in the extended source, including comparison with optical and radio features such as wisps. Also, the central point source associated with NP-0532 will be a $\geqslant 5\sigma$ signal.

The launch date for the high-resolution imaging experiment is February 1977. At that time both Cas A and the Crab will be visible. For the reasons discussed below, we consider the results obtainable from this experiment to be of significant scientific value. In particular, detailed structural data of the Cas A X-ray source can be used to understand the X-ray production mechanism for supernova explosions. The observed structure of the emitting shell can be compared with the predictions

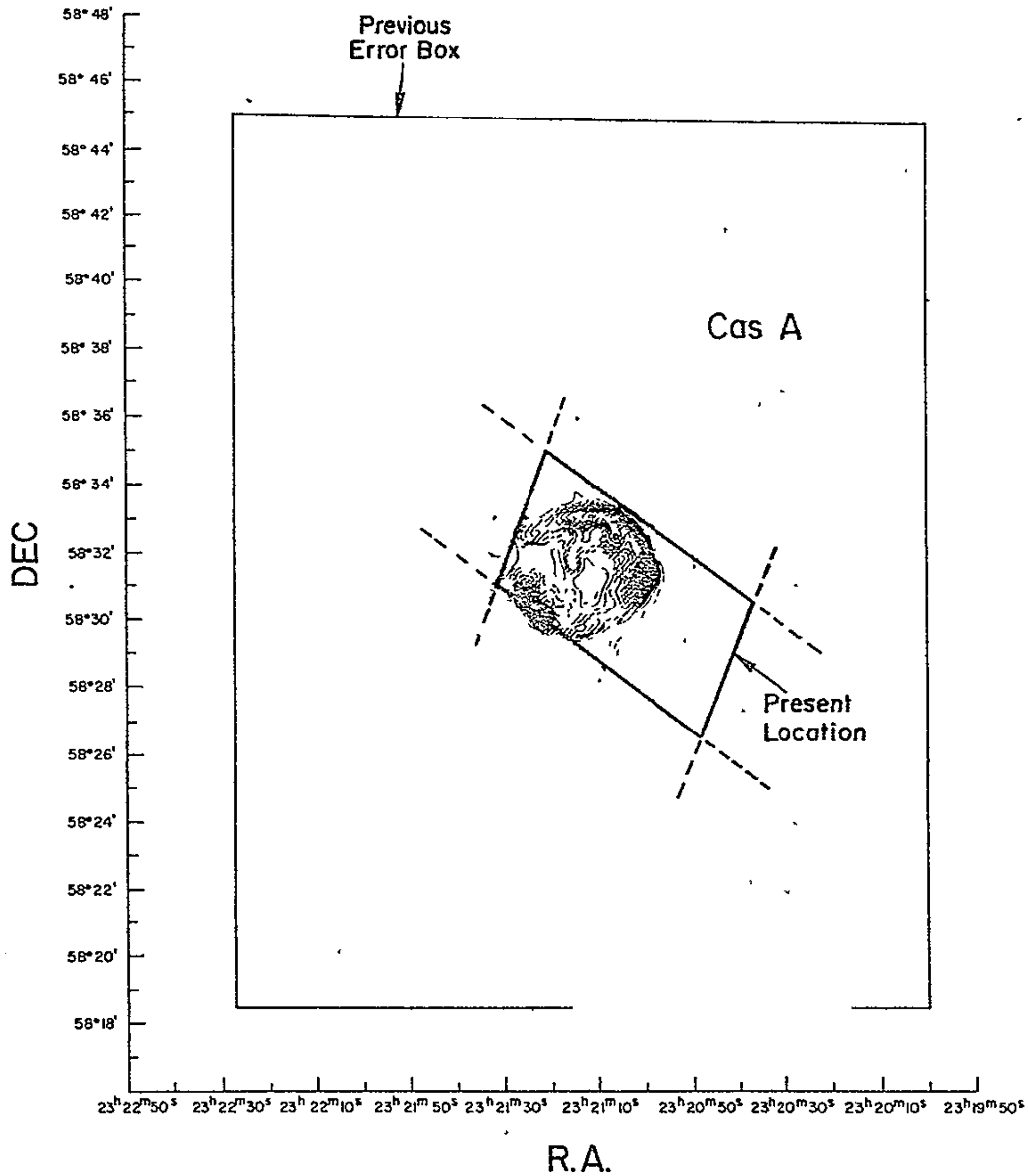


Figure 1. Source location for Cas A. The 1σ error box of the Uhuru X-ray location is labelled and is seen to agree very closely with the location of the supernova remnant. Outer rectangle, box of the previous X-ray location of Gorenstein et al. (1970). Radio contours from Ryle et al. (1965).

of SNR shockwave models to determine if they are at all applicable and whether there exists an ingoing shock as well as an outward moving one.

Also, an observation of Cas A with this experiment can determine whether a point-like X-ray emitter is present (down to about 10% of the total emission) due to a hot neutron star and/or a rapidly rotating neutron star (pulsar) left by the original supernova explosion. Pulsars are known to exist in the Crab and Vela nebulae, and there is evidence for a central component in the Cygnus Loop (Rappaport et al. 1973).

The observations of the Crab Nebula will be important for a study of the X-ray emitting structure. This structure is probably similar to the optical and radio wisps. Observations at X-ray wavelengths will allow us to build more accurate models of the cosmic ray electron acceleration and propagation within the nebula. It will be particularly exciting if an X-ray feature were found that actually showed a connection to the pulsar. This would directly relate the high energy cosmic ray electrons in the nebula to the pulsar. In any event, such a study is extremely important to the understanding of the origin of cosmic rays in the Galaxy. Also, the pulsar in the Crab Nebula appears to be an erratic variable as well as an X-ray pulsar (Forman et al. 1974). Our observations will be able to detect such an erratic variability, and thus we will be able to substantiate the results of Forman et al. Also, if the pulsar contained a soft D.C. component, our observations would be able to detect it.

In conclusion, a rocket flight in February 1977 to observe both Cas A and the Crab Nebula will provide very interesting scientific results. It should be obvious that these observations could also be performed with the HEAO-B telescope, with its larger area and longer exposure times. There are several reasons, however, for attempting these observations in early 1977. The observations of the extended supernova remnants can tell us about the limiting performance of a high-resolution telescope as well as about X-ray phenomena in the sources themselves. This can greatly impact the HEAO-B observing program and data analysis system develop-

ment, particularly concerning the unfolding of the telescope response function. Also, the results might be quite unexpected, leading us to new ways of thinking about the use of HEAO-B in particular and X-ray astronomy in general. In addition, since the X-ray imaging detector to be used in this rocket payload is identical to the HEAO-B detector, a great deal can be learned regarding detector noise and background.

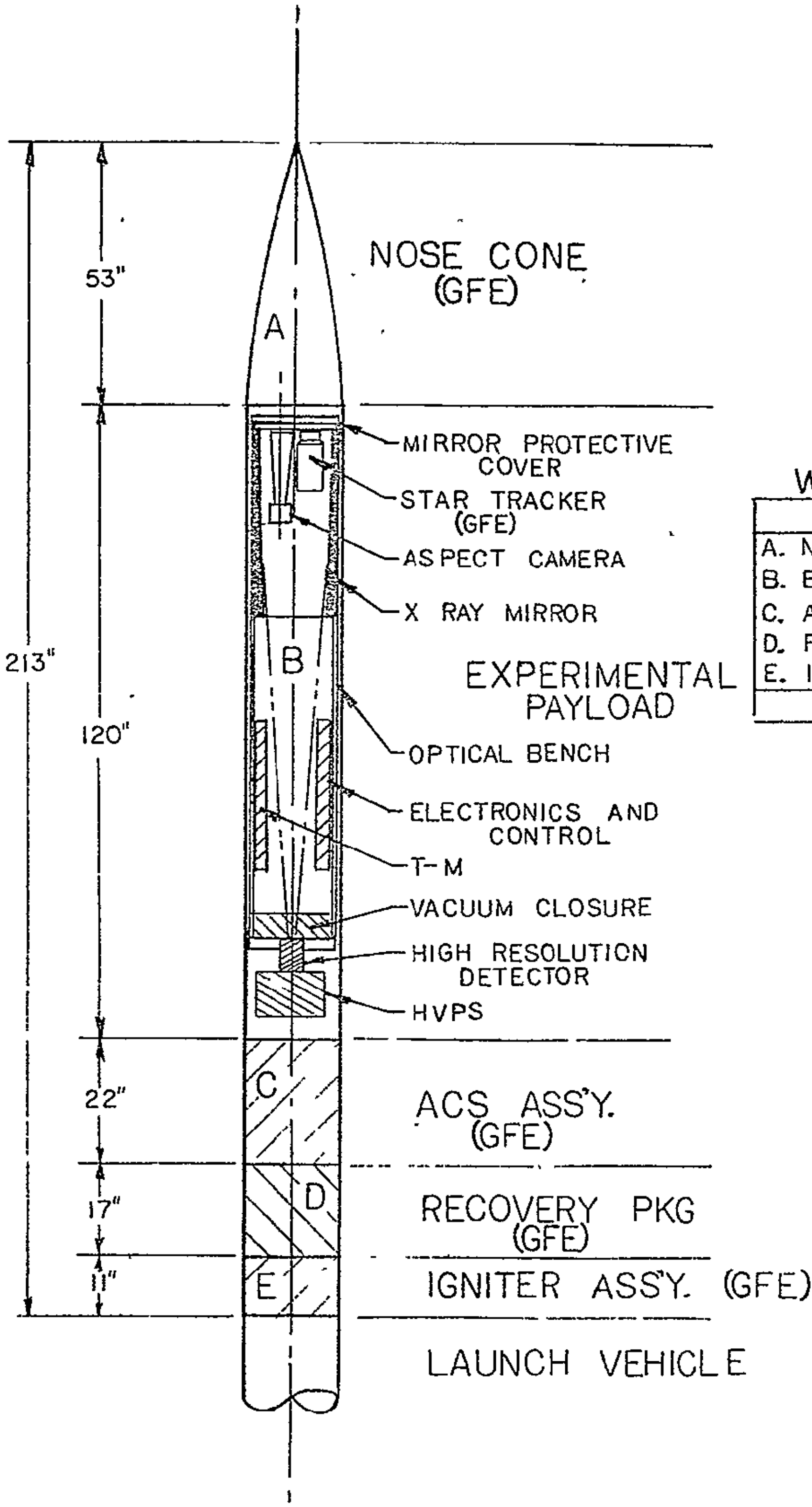
3. TECHNICAL DESCRIPTION

The three basic parts comprising the payload are the scientific instrumentation section, the attitude control section, and the recovery section. Both the attitude control section and the recovery system are government furnished equipment and engineering details about these will not be presented in this proposal except to summarize the requirements on the attitude control system. The payload has been baselined using an Astrobee F launch vehicle with the following characteristics:

Outside diameter:	17.26 in.
Maximum ID of extension:	17.01 in.
Maximum diameter extension clears:	16.26 in.
Maximum payload length:	200 in.
Minimum total payload weight:	240 lbs.

A preliminary weight estimate, based on our Aerobee 170 payload, is about 700 lbs, including ACS, telemetry, and recovery system. This would result in a useable flight duration of about 200 seconds.

A sketch of the proposed payload is shown in Figure 2. The major elements shown are discussed in the following sections and include: X-ray mirror (3.1); Mirror protection device (3.2); optical bench and payload housing (3.3); High Resolution Imaging System Detector including detector, crossed grid readout, processing electronics, high-voltage supplies, and vacuum systems (3.4); ACS system including electronics, gas, and fine pointing sensor (3.5); aspect camera and fiducial light system (3.6); and electronics and control system, including a clock and telemetry unit (3.7). Also shown but not discussed are the recovery system, the separation ring, and the experiment batteries.



WEIGHT SUMMARY

ITEM	WEIGHT
A. NOSE CONE	38 - LB.
B. EXPERIMENT	394
C. A.C.S. ASS'Y.	105
D. RECOVER PKG.	70
E. IGNITER ASS'Y.	80
TOTAL	687 - LB.

Figure 2. Proposed payload layout and weight summary.

3.1 X-Ray Mirror

Incoming X-rays are doubly reflected at grazing incidence off the telescope surfaces of a Wolter-type I mirror that uses confocal paraboloidal and hyperboloidal surfaces for imaging. The mirror will be provided by the HEAO-B program, after it has been extensively calibrated as the HEAO-B X-ray test mirror. HEAO-B tests will include measurements of reflection efficiency and scattering as functions of wavelength and angle of incidence as well as measurements of depth of field.

The X-ray test mirror has a 12-inch diameter at its center, segment lengths of 18 inches each, a focal length of 77 inches, and a grazing angle of 1.1°. The weight of the mirror including its mounting flanges (also supplied by the HEAO-B program) is estimated at 100 lbs.

Figure 3 shows the calculated effective area of this mirror as a function of energy for a source on axis, and for several off axis values. (The geometric area of the mirror is 81.5 cm^2 and maximum effective area for on-axis X-rays at low energies is 68.5 cm^2.) The RMS blur circle radius (i.e., the radius of the circle containing 69% of the transmitted intensity when we include geometric optics diffraction and scattering effects) is tabulated for several angles off the optical axis in Table II.

TABLE II

Distance from Optical Axis	RMS Blur Circle Radius
0 arcmin	2 arcsec
2	2.1
5	3.8
10	13.0
20	49.1

We note that within 5 arc minutes of the optical axis, scattering effects dominate the blur circle radius and actual performance could be better than the conservative estimates used.

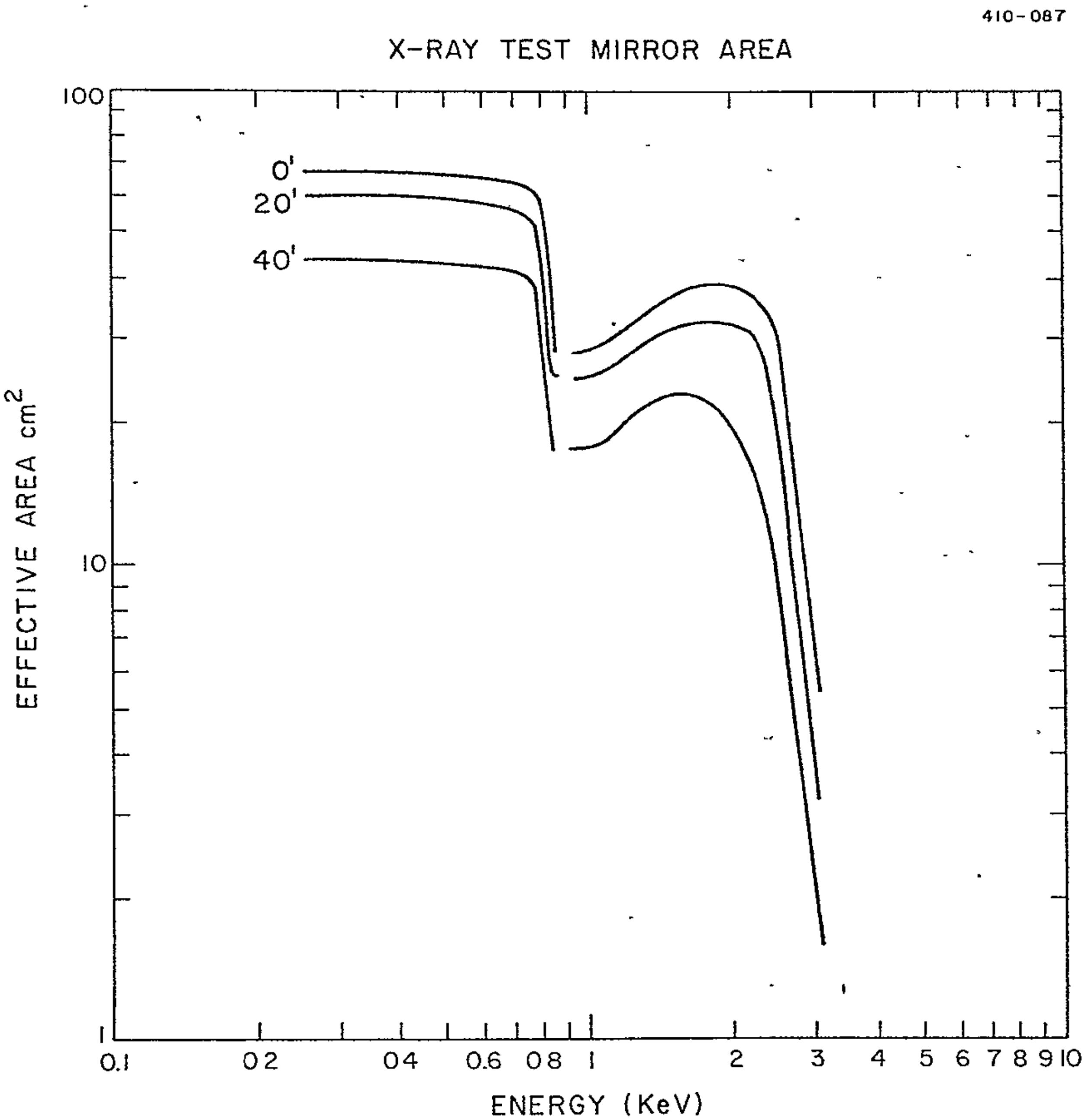


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Figure 3. Effective area of HEAO-B X-ray test mirror as a function of energy for a source at 0, 20, and 40 arc minutes from the mirror axis.

3.2 Mirror Protection Device

A mirror protection device will be required for safe recovery of the payload. This will consist of a mirror closure and a crushable collar to act as a shock absorber. It is our intent to adequately protect the X-ray mirror so that several reflights of this payload will be possible.

3.3 Optical Bench and Payload Housing

An optical bench is required to maintain alignment among the X-ray test mirror, HRI detector, and aspect camera. The optical bench (together with the payload housing) should maintain alignment to 2 arc seconds under the launch dynamic loads and aerodynamic heating. (The current optical bench on the Aerobee 170 payload can maintain the alignment to $\leqslant$ 10 arc seconds.) Fiducial lights as described in Section 3.6 will be used to correlate the X-ray axes to the aspect camera axes to the 2 arc second tolerance required. The optical bench might not be required to carry the full loads but, instead, be used to preserve the dimension along the focal length and to prevent twist. The ACS Fine Pointing Control Sensor (FPCS) must also be mounted to the optical bench and held to a tolerance of 10 to 30 arc seconds to ensure proper pointing.

We propose that SAO design and build the optical bench and that the GSFC rocket vehicles section provide the payload housing consisting of the cylindrical mechanical structure and door doublers as appropriate. This is a cost effective step that takes

advantage of GSFC facilities and expertise in this area. SAO will provide design inputs for the payload housing and will integrate the optical bench to this structure.

3.4 HRI Detector System

The major elements of the HRI system are the X-ray detector, crossed wire grid readout, vacuum housing, high-voltage system and processing electronics.

The X-ray detector consists of a pair of microchannel plates (MCP's) with a bias angle of $\sim 12^{\circ}$. The first MCP acts as an X-ray photocathode and electron amplifier, the second MCP continues the electron gain until an overall gain of $\sim 10^{8}$ is obtained. The cloud of electrons leaving the MCP stack is intercepted by the wires of the position sensitive readout and the resultant signals are fed to the processing electronics through a series of vacuum feed throughs. Appendix B of this proposal is an article by Kellogg et al. which describes the HEAO-B HRI system. The unit we propose to use in this rocket payload is a brassboard of the HEAO-B HRI. There will be several modifications made to this unit, most significant will be the use of a non-programmable HV power supply for the MCP's ($\sim$ 4000 V) and a repackaging of the brassboard processing electronics as necessary for flight.

The HRI detector will have a 25 mm active diameter with a readout accuracy of $\sim 20\mu m$. This corresponds to a field of view of $\sim$ 45 arc minutes with $\sim$ 2 arc second resolution. For images within a $\sim$ 5 arc minute radius of the mirror axis, the experiment is capable of achieving 2 arc second images. Typical quantum efficiencies of MCP detectors are given in Table III.

The background event rate from MCP's at room temperature is sufficiently low so that cooling of the detector will not be required. The measured background rate for MCP's is $\sim$ 10 cts/sec over the entire 25 mm active area or less than 1×10^{-6}

Table III

Energy (keV)	Quantum Efficiency (%)
0.28	17
0.8	17
1.5	6.8
2.3	5.5
3.0	4.0

80/1 = L/D Varian MCP's operating in saturated pulse height distribution mode with 3° to 5° incident angle X-rays with 4:1 pulse height dynamic range.

cts/sec per 20 μm resolution element. Thus the experiment is completely signal limited and can yield accurate results with only a few events detected.

3.5 Attitude Control System

The ACS control electronics, gas, rate integrating gyros (RIG's), and fine pointing control sensor (FPCS) are GFE. The present system used on the Aerobee 170 was able to point stably with a drift rate of ~ 1 arc sec/sec. Such a system would be satisfactory for keeping a source within ~ 2-5 arc minutes of the optical axis for ~ 200 seconds, provided the initially pointing accuracy is better than 30 arc seconds. The jitter due to the gas jets can be minimized by allowing drifts up to 30 arc seconds or more before making corrective maneuvers. Also, high-pressure ACS jets can be used to make large, rapid maneuvers between targets while low-pressure gas jets can be used for fine correction maneuvers.

The ACS system (STRAP IV) used with the Aerobee 150-170 payload, should be adequate for the requirements of the proposed payload. In order to point the telescope payload to 10-30 arc seconds accuracy, it is possible that the FPCS and ACS gyros will need to be mounted to the optical bench. We will explore other possible options as the payload design progresses.

3.6 Aspect Camera

The aspect camera will be similar to that used in the Aerobee 150-170 payload with the primary difference being an increase of a factor of 4 in the lens focal length. This reduces the field of view to ~ 1 x 1.5°, necessitating a larger diameter lens so that several stars will be detectable in the field of view. Detailed calculations will be required to determine the appropriate f/number for the lens. We baseline an exposure time of 0.5 seconds with the Flight Research Model 3B camera and film used in the Aerobee 150-170 program. (The 0.5 second exposure time is determined

in part by the drift limitation of 1 arc sec/sec.)

The fiducial light system used to reference the star field coordinate system with respect to the X-ray telescope system is similar to that used in the Aerobee 150-170 payload and is shown schematically in Figure 4. Three light sources are mounted to the HRI detector assembly and are observed after reflection by a corner cube in the aspect camera. A relay lens is also required, mounted at the central plane of the X-ray mirror. Figure 6 illustrates how the fiducial lights are used to relate the X-ray source image to the aspect star images.

3.7 Control Electronics and Telemetry

The electrical system of the payload will consist of

(1) timing circuits and payload controls
(2) power control and switching
(3) monitor circuits and commutator
(4) camera control
(5) pyrotechnic circuits
(6) batteries
(7) HRI system high voltage
(8) HRI system processing electronics
(9) vacuum door control
(10) telemetry

Also required is a GSE control console external to the payload to provide operation of the payload.

Timing circuits are required for proper in-flight operation of the experiment. Prime commands for the experiment are received from either timers in the telemetry instrument package or the ACS system. Timer switch closures are also provided

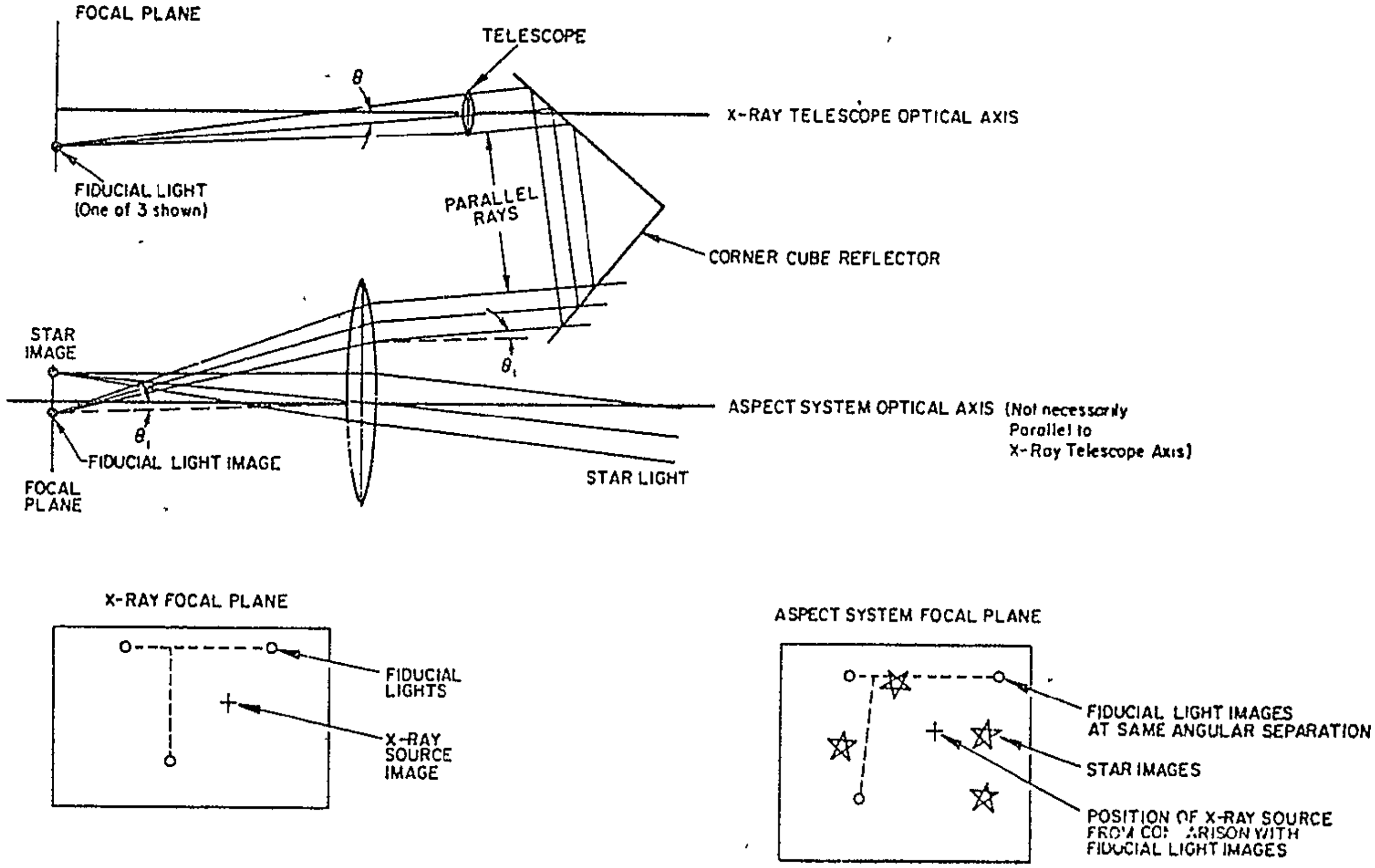

Figure 4. Aspect system optical concept including the technique used to correlate the X-ray telescope focal plane positions with the aspect system star field image.

by the experiment timing circuits located on the main electronics panel. In-flight control functions may include:

lockout off

high voltage power supply on

coast

start despin and erect

payload separation

stabilize

remote adjustment

start camera

start first maneuver

open vacuum door

continue maneuvers

close vacuum door

close mirror protector

shut off high voltage

All timer commands operate through multi-pole latching relays except for the lockout function. One coil on each relay is tied to a common reset, which is energized by lockout or externally from the control console. The multiple inputs to the control coils of each relay are electrically isolated by diodes.

The batteries are to be GFE and the power control and switching circuit will control regulate, and distribute low-voltage power as required. Monitoring functions such as low-voltage power, high-voltage power, logical states of relays, temperatures, etc. will be carried out as in the Aerobee 150-170 payload. The data are obtained as a commutated channel using a 29 segment, 2.5 RPS, Model 951-4 Datametrics commutator.

The aspect camera film transport mechanism will be the same clutch-brake motor combination as in the Aerobee 150-170 payload. The electronics panel will contain the circuit module that provides the timing, pulse shaping, and driving circuits for the motors. In conjunction with the pulsing of the camera motor, the circuit module will also actuate the fiducial lights in the X-ray focal plane. Also, coding lights in the aspect camera are actuated to synchronize the X-ray and aspect information. The timing module operates whenever power is turned on; however, the camera and lights operate through a start camera command.

A pyrotechnic circuit will be required to actuate the mirror protection cover, if a device similar to that employed in Aerobee 150-170 payload is used. The Aerobee 150-170 pyrotechnic system uses redundant bridgewires in Model 2801 Holex guillotine cutters, which are electrically actuated. There is also redundant timing and batteries. An arming switch is closed before launch, and the safety pin is manually extracted from the Raymon timer thereby arming the circuit. As an additional safety precaution, a lockout relay is provided that prevents the command relays from firing the guillotines until the lockout timer command actuates the lock-out relay. This represents an in-flight arming function. Also, the bridgewires are shorted and held at ground potential until actuation. The circuits conform to range safety requirements.

The HRI system high voltage processing electronics, and vacuum door have been discussed in Section 3.4. The HRI X and Y position will use 12 bits/each per event, while 3 or 4 bits of pulse ehight data and up to 12 bits of timing information will also be provided. A clock will be required to provide time tagging capability, and a coding capability will also be needed to correlate X-ray data to the aspect camera. Appropriate interface electronics between the HEAO-B brassboards and the telemetry system will be required.

The telemetry system will be furnished GFE and serviced by NASA personnel. A pulse position modulation (PPM) system will be used with a 10-KHz sampling rate -- data channels will need to be assigned and the timing accuracy of real-time transmission for tagging events will need to be assessed. The 10-KHz rate will be adequate for our requirements.

4. SCHEDULE AND STATEMENT OF WORK

SAO will provide all personnel, facilities and material except for government furnished property as listed in Section 5 and support services associated with a sounding rocket program to accomplish the following tasks during FY 1977.

1. Determine necessary modifications to HEAO-B brassboard HRI detector system
2. Repackage the HRI electronics for flight
3. Construct the experiment control panel
4. Interface payload readouts to the rocket telemetry
5. Revise the Aerobee 170 payload GSE as appropriate
6. Design and construct HV distribution system for the HRI
7. Design and construct the fiducial light system
8. Assemble the payload, align and calibrate
9. Support for integration and testing of the payload at GSFC-SRD
10. Field support for the flight of this payload in winter 1977
11. Analysis of data from this flight.

The XTM and HRI will be required as GFE to this program by 1 September 1976 with the understanding that the calibration and testing of the XTM-HRI combination represents a test of the X-ray mirror by the HEAO-B program as part of the HEAO-B mirror evaluation effort. This testing is planned to take place during October and if necessary November of 1976 at the X-ray test facility at MSFC in Huntsville, Alabama. After calibration, the experiment payload will be integrated with the ACS system at GSFC-SRD and subjected to environmental testing. The payload will be shipped to WSMR at the end of December or January in anticipation of a launch in January or February 1977. The target sources will be Cas A and Crab.

The data obtained from this flight will be analyzed in the following months at SAO and reflights of the payload will be scheduled in FY 1978 prior to and during the flight of HEAO-B

5. GOVERNMENT-FURNISHED PROPERTY AND SUPPORT SERVICES

We request the following GFE items for the Astrobee F high resolution payload.

Nose cone

Payload housing

Beacon

Commutator

Timers and inertia switches

ACS

Recovery

Experiment batteries

Fine pointing control sensor

Telemetry

WSMR Support

We also request the use of test facilities at GSFC for vibration testing of the payload and major subassemblies.

The program will require the transfer of the XTM by October 1, 1976 and the HRI by July 1, 1976 from contract NAS8-30750. SAO will also require the availability of various parts and systems from the Aerobee 170 payload/GSE, currently at SAO under contract (NAS5-23322).

6. CONTRACTUAL AND COST SECTION

The Smithsonian Institution is an independent establishment that is under a Board of Regents. The Institution proper, as distinguished from executive agencies of the Government, was created when James Smithson, an Englishman who dedicated his fortune to the increase and diffusion of knowledge among men, designated the United States of America as his trustee to accomplish that objective. The trust was accepted by Congress.

The Smithsonian performs research, educational, and other special projects supported by grants and contracts awarded under those cost principles of the Federal Procurement Regulations and the Armed Services Procurement Regulation that pertain to educational institutions (Subpart 1-15.3 and Section 15, Part 3, respectively).

It is audited by the Defense Contract Audit Agency, Silver Spring, Maryland. This project is being proposed by the Smithsonian as an educational institution.

The Charter of the Smithsonian Institution carries a mandate for the "increase and diffusion of knowledge among men." Therefore, any grant or contract that may be awarded as a result of this proposal must be unclassified, in order not to abridge the Institution's right to publish, without restriction, findings that result from this research project.

Considering the nature of the proposed effort, it is requested that a supplement to research grant NSG 5091 with letter-of-credit funding with educational institutions be awarded to cover the proposed project in accordance with Part IV of GSA Federal Management Circular No FMC 73-7 dated 19 December 1973. Pursuant to Part III of GSA Federal Management Circular No. FMC 73-7, it is requested that title to all equipment purchased or fabricated under the proposed grant be vested irrevocably in the Institution upon acquisition.

In accordance with an agreement between the Headquarters of Naval Material Command, Washington, D.C., and the Smithsonian, the Institution operates on a predetermined overhead rate with carry-forward provisions, and the indirect costs are computed as a percentage of total direct costs. The overhead rate proposed herein is 31% which has been approved as a predetermined rate through 30 September 1976 and as a provisional billing rate thereafter.

ESTIMATE OF COST

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Personnel Compensation	$ 38,935
Personnel Benefits	6,435
Travel	9,974
Transportation of Things	2,000
Real-Property Rental	6,882
Communications	1,280
Postage	150
Printing and Reproduction	622
Other Services	2,600
Computing Services CDC 6400 (10 hrs @ $172/hr)	1,720
Supplies and Materials	9,000
Equipment	8,000
Total Direct Cost	87,598
Indirect Cost @ 31%	27,155
Subtotal	114,753
Less Cost Sharing (from non-Federal sources)	(200)
Total Estimated Cost	$114,553

VITAS AND BIBLIOGRAPHIES

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VITA

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Physicist

Education:

Milan University, Ph.D., Physics (1954)

Positions Held:

1954-56	Assistant Professor of Physics, University of Milan
1956-58	Research Associate, Indiana University
1958-59	Research Associate, Princeton University
1959-	American Science & Engineering, Inc.; Board of Directors, 1966; Executive Vice President, 1969
1970-72	Associate, Harvard College Observatory
1973-	Associate Director for High-Energy Astrophysics Division, Center for Astrophysics, Smithsonian Astrophysical Observatory
1973-	Professor of Astronomy, Harvard University

Professional Societies:

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American Association for the Advancement of Science
American Astronomical Society
American Physical Society
International Astronomical Union
National Academy of Sciences

General Fields of Investigation:

Space physics, x-ray astronomy, high-energy astrophysics

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